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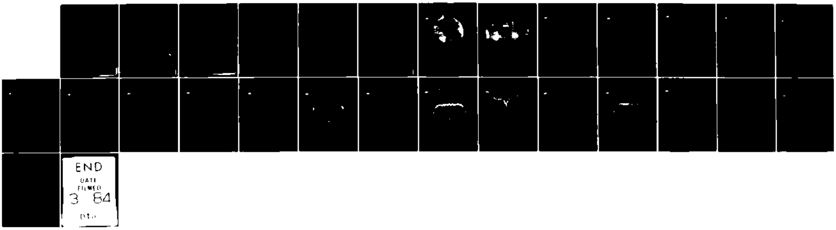

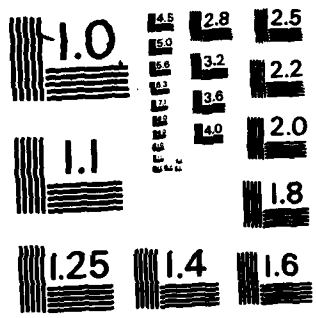

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TRISTEN/FRAM IV CW SPATIAL COHERENCE AND TEMPORAL STABILITY

An Invited Paper Presented at the Special Session on Arctic Acoustics at the 106th Meeting of the Acoustical Society of America, 3 November 1983, San Diego, California

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PREFACE

This document was prepared under the sponsorship of the Office of Naval Research, Program Manager, Dr. L. Johnson, (Code 425AR) under NUSC Project A64006 and under the sponsorship of the Naval Sea Systems Command, Undersea Warfare Technology Office, D. Porter (Code 63R), NUSC Project A64011, NUSC Principal Investigator, Dr. F. R. DiNapoli (Code 01Y).

Reviewed and Approved: 1 February 1984

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This document presents the oral and visual presentation entitled "TRISTEN/FRAM IV CW Spatial Coherence and Temporal Stability," presented at the 106th Meeting of the Acoustical Society of America at the special session on Arctic Acoustics held on 3 November 1983 in San Diego, California.

The TRISTEN-82/FRAM IV experiment was a multifaceted experiment investigating acoustics in the Arctic. This paper focuses on the spatial coherence cont

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and temporal (frequency) stability of acoustic signals transmitted and received between fixed ice camps separated by approximately 130 nmi. A high powered, low frequency (NUSC HLF-3 Arctic) hydroacoustic source transmitted stable CW tones of 1 hour or more at various frequencies from 5 to 200 Hz during April 1982. These signals were received on an X-shaped array having an aperture of 1200 m on each leg. The array was operated by the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution. The spatial coherence of frequencies below 100 Hz, both broadside and endfire to the source, were found from normalized sensor pair cross correlation, corrected for signal-to-noise ratio. Total and 3 dB down received signal bandwidths were found using complex demodulation and FFT with a resolution to a fraction of mHz, followed by cumulative energy analysis in the frequency domain. The experimental setup, data analysis procedures, and results are presented.

cont next page

TD 7095

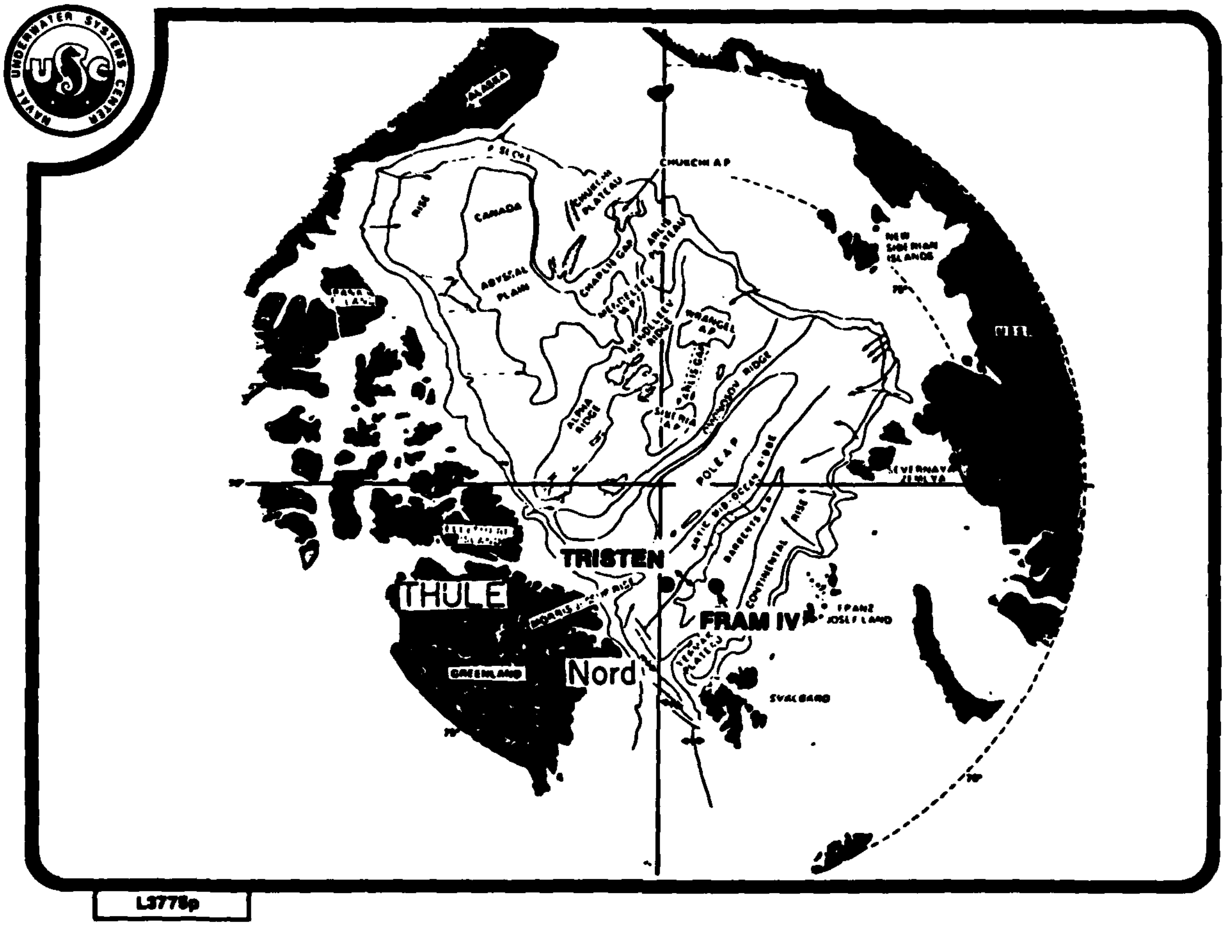
TRISTEN/FRAM IV CW SPATIAL COHERENCE AND TEMPORAL STABILITY

INTRODUCTION

Cont The major conclusion ~~of this paper~~ is that the Arctic is a very stable environment for low frequency acoustic signals. This observation was first made two decades ago by Buck, Mellen, and Kutschale based almost exclusively on broadband explosive data. One of the objectives of the TRISTEN/FRAM series of experiments, which were ONR-sponsored joint ventures between NUSC and MIT, was to quantify and extend earlier observations to narrowband low frequency continuous wave (CW) experiments. The results of the first TRISTEN/FRAM experiment conducted in 1980 have been reported in the journal of this society by Mikhalevsky. This paper focuses on the temporal stability and spatial coherence of low frequency CW signals transmitted in the Eastern Arctic as part of the TRISTEN-82/FRAM IV experiment.

- First vugraph, please. -

A-1

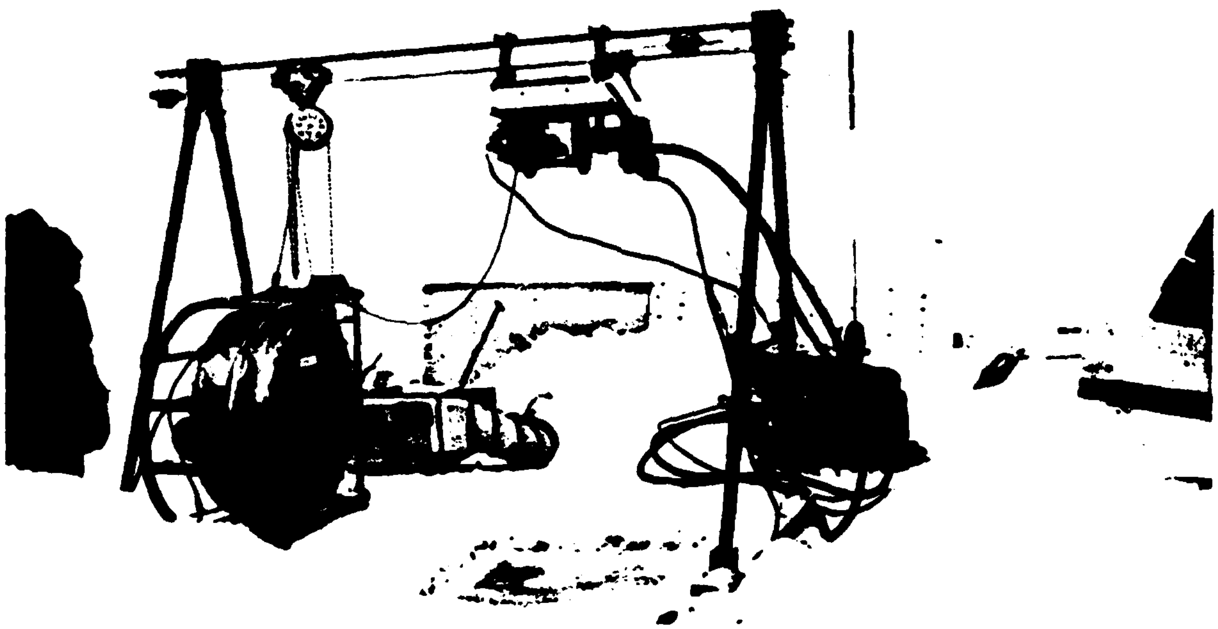


VUGRAPH 1

Stable, high powered, low frequency CW tones (usually of 1 hour duration) were transmitted from the NUSC HLF-3 Arctic source suspended at 90 m through multiyear ice approximately 4.3 m thick at Ice Station TRISTEN, which was located over the extension of the mid-Atlantic ocean ridge.

The signals were received at Ice Station FRAM, located in the Barents Abyssal Plain, on a horizontal X-shaped array that was suspended at 90 m . This array was designed and operated by MIT/WHOI. Arthur Baggeroer of MIT was the chief scientist at FRAM during this phase of the experiment. He and his colleagues at MIT/WHOI deserve much of the credit for the success of the exercise. Both ice stations drifted slowly over the month of April with a nominal separation of 130 nmi.

- Next vugraph, please. -

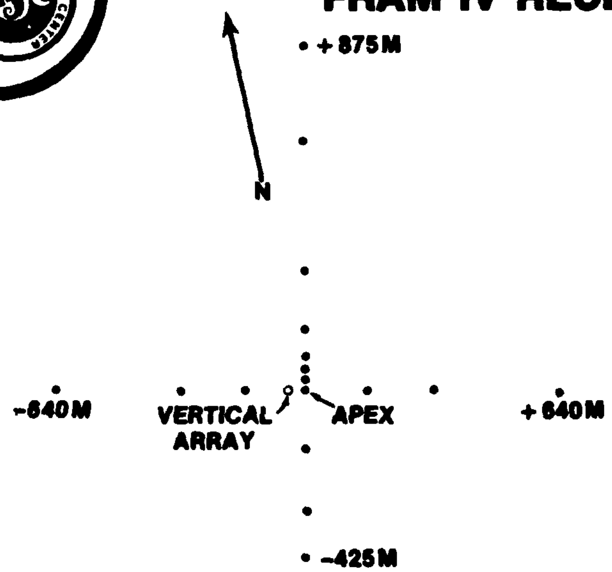


VUGRAPH 2

The flavor of what many of you are missing by conducting experiments in such temperate environments as Bermuda and the Mediterranean is provided along with an indication of the size of the NUSC HLF-3 Arctic source. It weighs approximately 1 ton and stands 1.22 m high. To suspend the source at 90 m we first had to excavate approximately 8 tons of ice from a hole measuring 1.22 x 2.13 x 4.2 m deep.

- Next vugraph, please. -

FRAM IV RECEIVING ARRAYS



HORIZONTAL ARRAY

24 ELEMENTS
DEPTH = 90 METERS
MINIMUM SPACING = 20M
E-W APERTURE = 1240M
N-S APERTURE = 1300M

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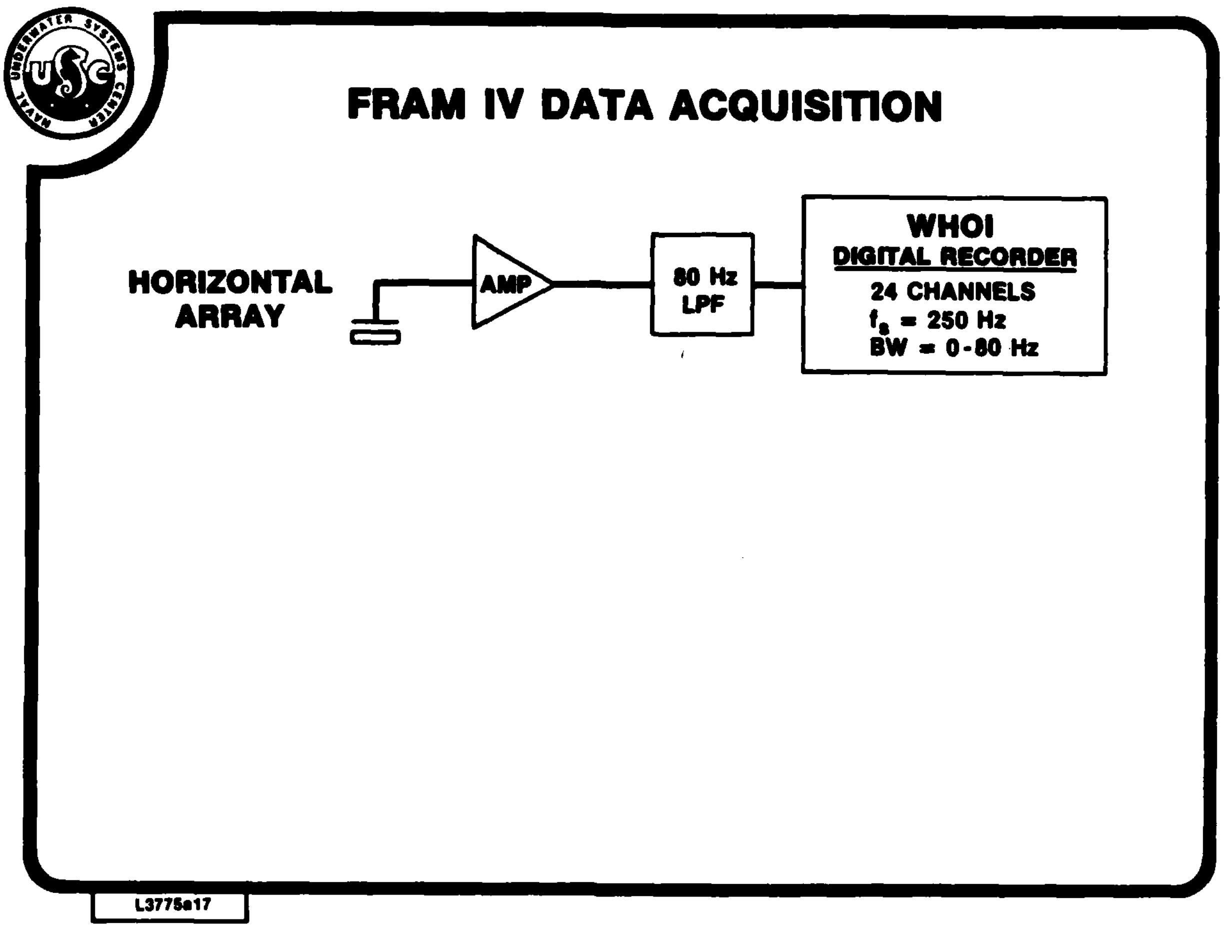
VUGRAPH 3

The MIT horizontal array had an X-shaped pattern with a total aperture along each leg of 1200 m. By using separate portions of the X it was possible to obtain both broadside and endfire results to the fixed source at TRISTEN. Possible sensor spacing combinations ranged from 20 to 1280 m.

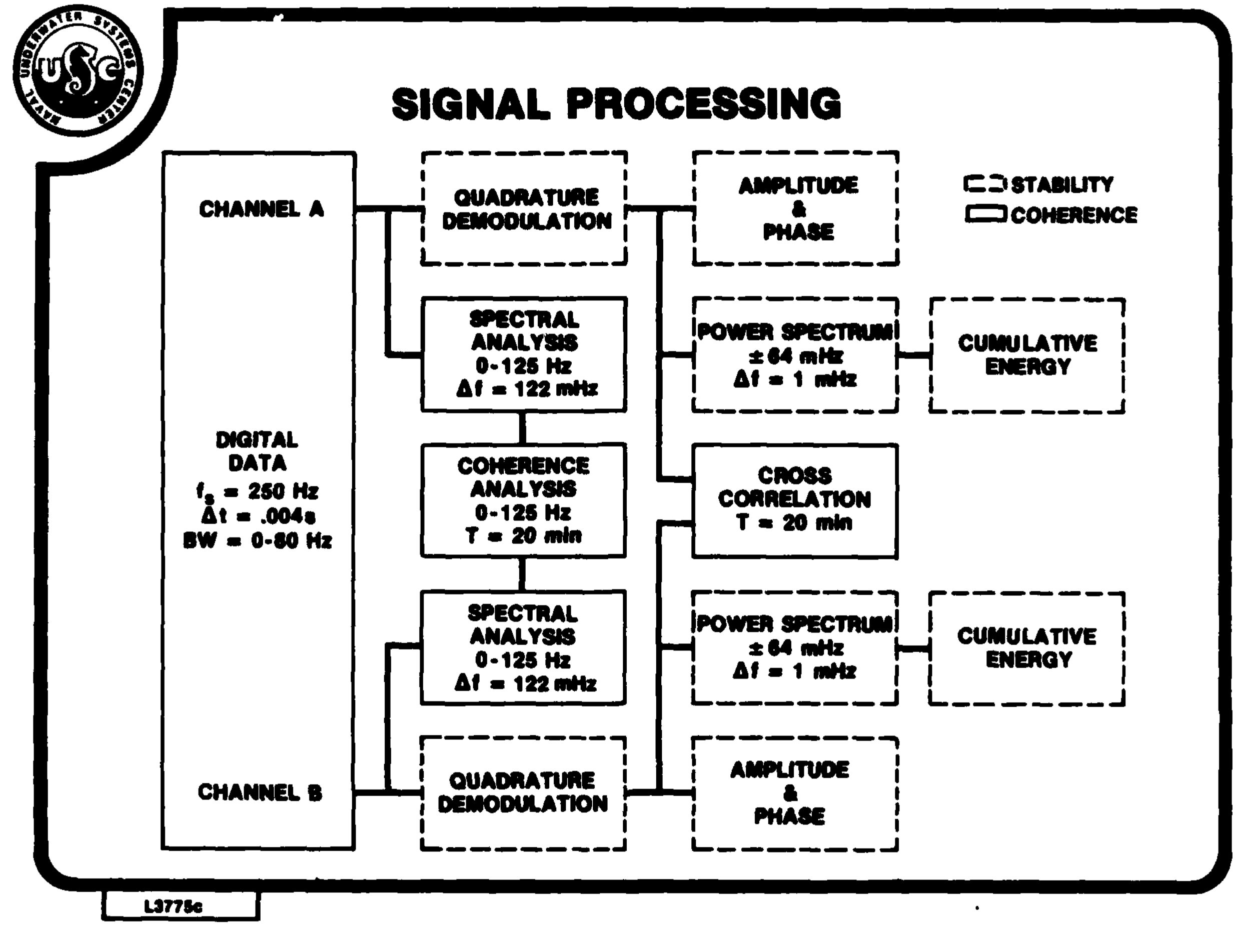
- Next vugraph, please. -



VUGRAPH 4

Shown in this vugraph is a schematic of the digital recording setup at FRAM. Individual hydrophone outputs were passed through a gain ranging amplifier, low pass filtered at 80 Hz, digitized at 250 Hz, and recorded on 20 minute digital tapes.

- Next vugraph, please. -



VUGRAPH 5

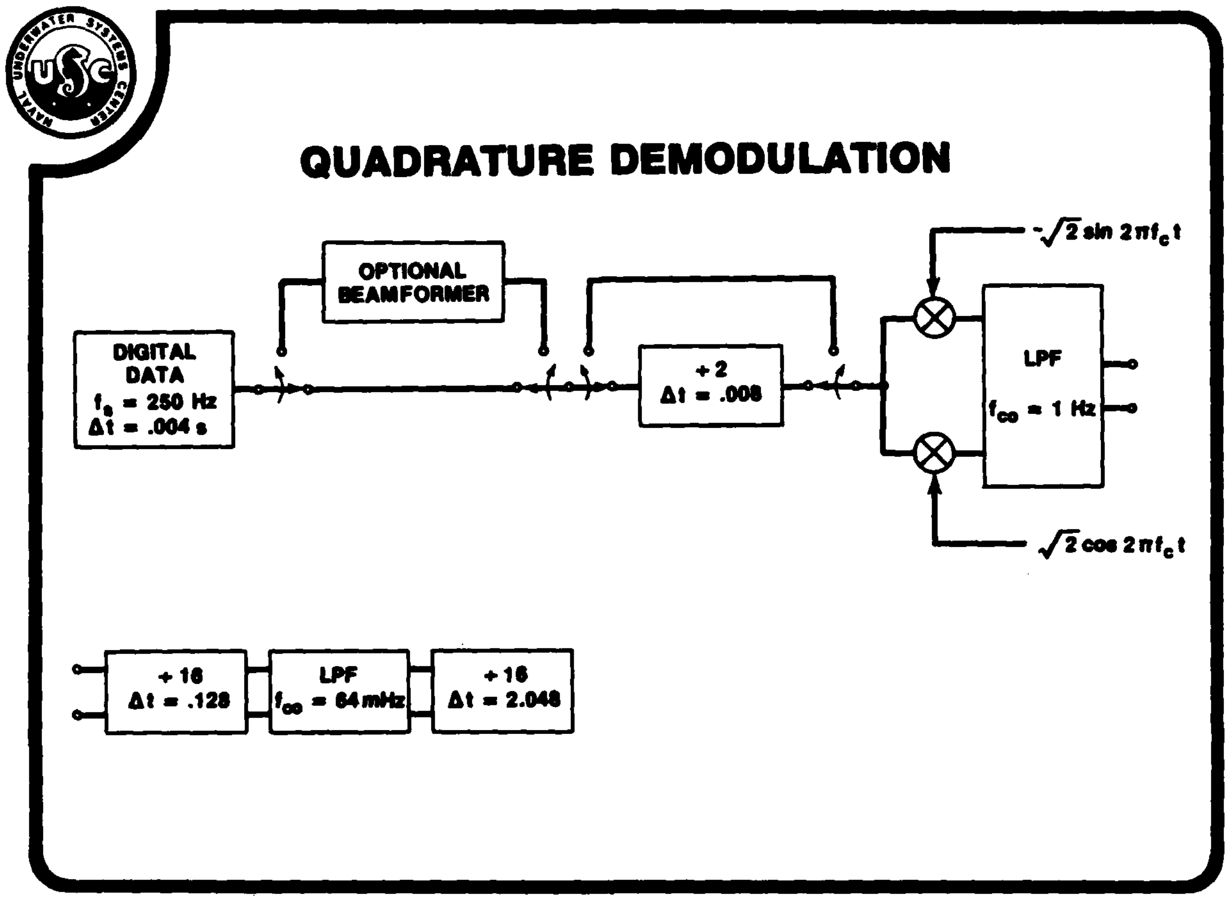
Shown are the various steps in the processing for either the stability analysis, shown by the dashed boxes, or the coherence analysis shown by the solid boxes.

The flow path for the stability analysis begins with quadrature demodulation of individual hydrophone outputs. The amplitude and phase quadrature components are plotted versus time, then recombined and the power spectral density is obtained in a 128 mHz band around the demodulation frequency. Next a cumulative energy analysis is performed to determine the received frequency smear.

When determining the spatial correlation, the output from the two hydrophones are first quadrature demodulated and then the complex signals are cross correlated over 20 minutes of data.

The spatial coherence is obtained by computing the power spectral density of two hydrophone outputs over 125 Hz with a frequency resolution of 122 mHz. The magnitude squared coherence function is obtained by averaging 128 estimates corresponding to a total time of about 17 minutes. The coherence values are corrected for signal-to-noise ratio and plotted versus separation distance.

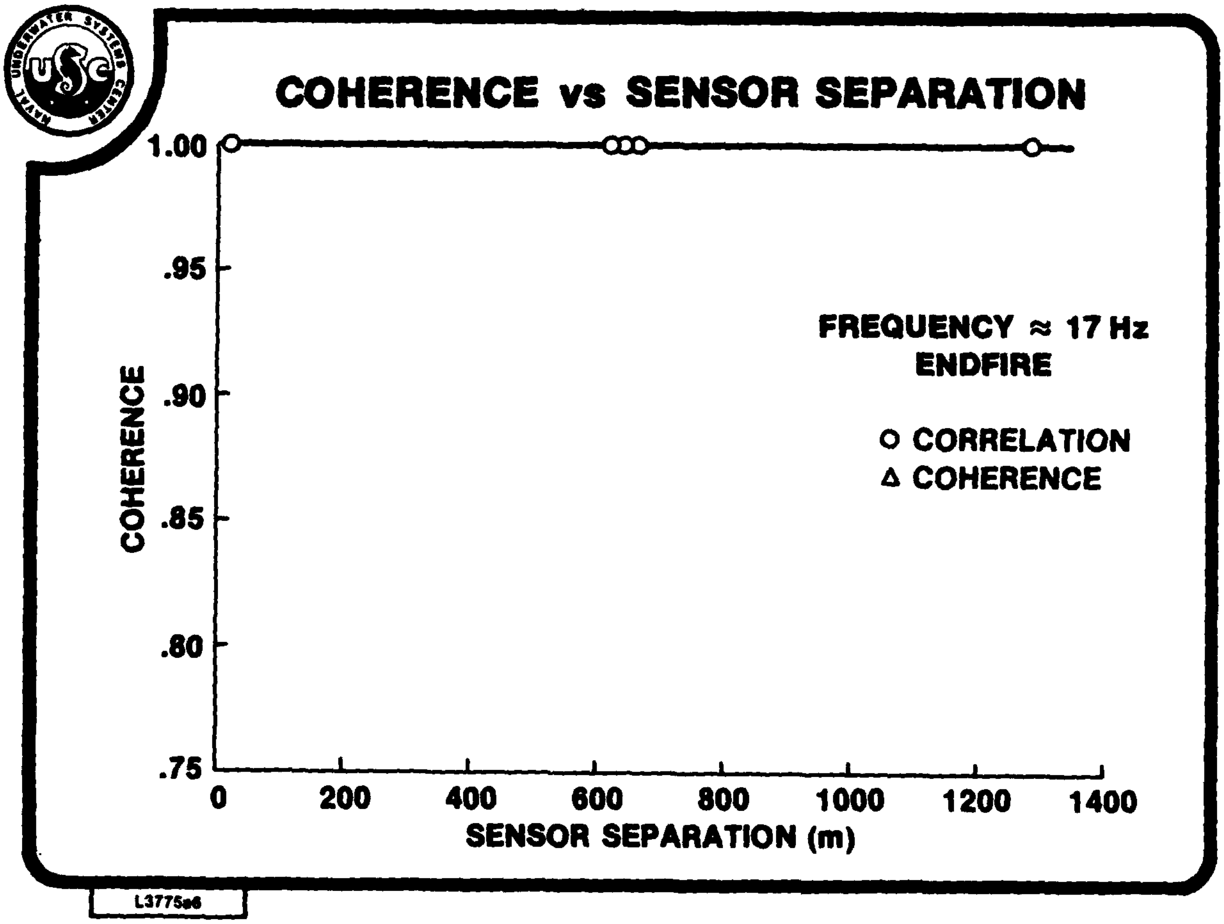
- Next vugraph, please. -



VUGRAPH 6

The details of the quadrature demodulation process are expanded in this vugraph. The option of beamforming was not used in the results to be shown. After decimation by 2, the recorded data are multiplied by the sine and cosine of the demodulation frequency. The quadrature components are low pass filtered at 1 Hz, decimated by 16, and low pass filtered again with a pass band of 128 mHz. The final operation is another decimation by 16. Thus, the original data ends up with samples spaced 2.048 seconds apart providing about 1757 data points for 1 hour of data.

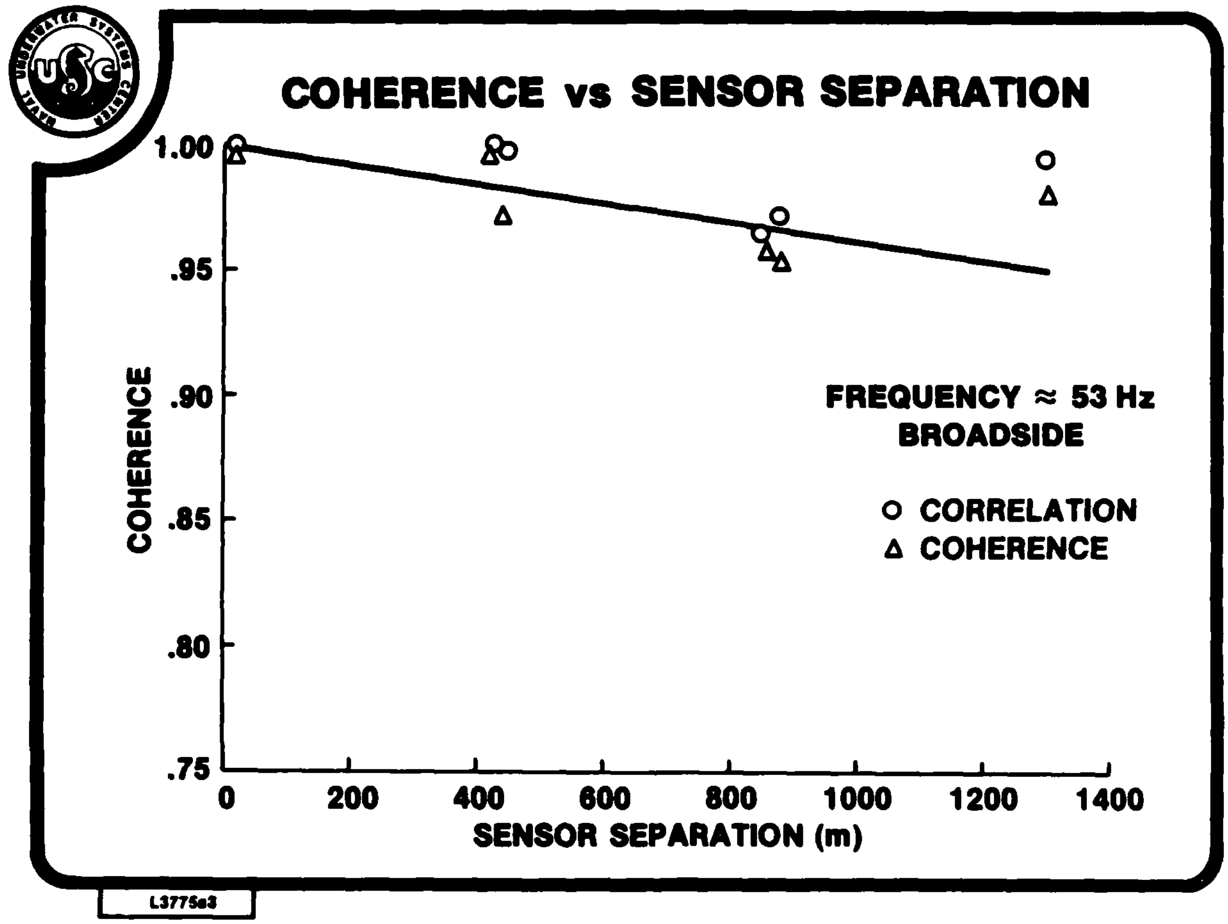
- Next vugraph, please. -



VUGRAPH 7

At 17.75 Hz the coherence is essentially unity out to the largest available separation distance with the endfire portion of the array. The result at broadside is identical to this. I call your attention to the vertical scale, which starts at 0.75. This scale will be used for all of the coherence plots to be shown.

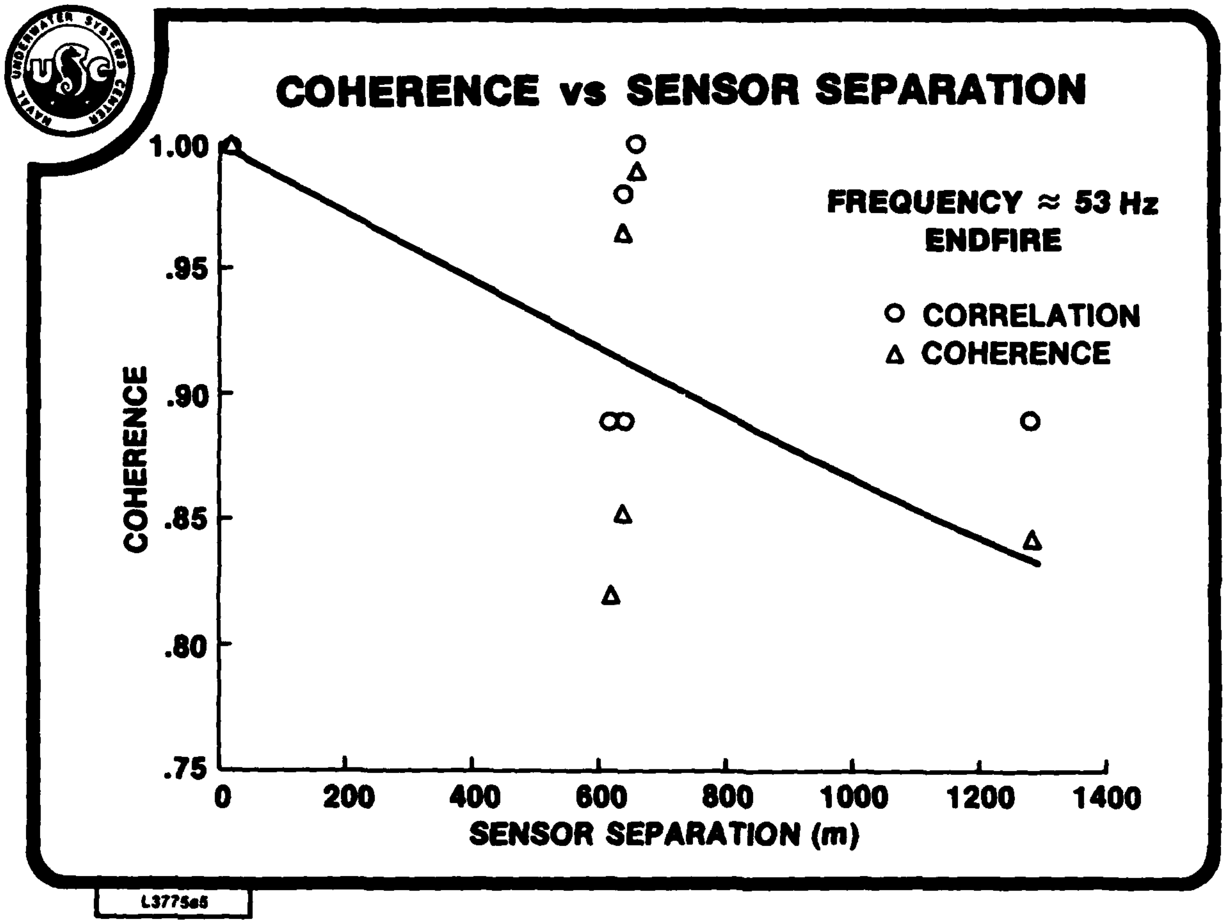
- Next vugraph, please. -



VUGRAPH 8

The broadside result at 53.25 Hz begins to show some slight degradation in coherence. The circles represent values obtained from correlation while the triangles result from the coherence calculation. The line is an exponential fit to the measurements. The lowest value found was 0.95.

- Next vugraph, please. -



VUGRAPH 9

The 53.25 Hz result at endfire shows a slightly lower trend with the lowest value in this case at about 0.8.

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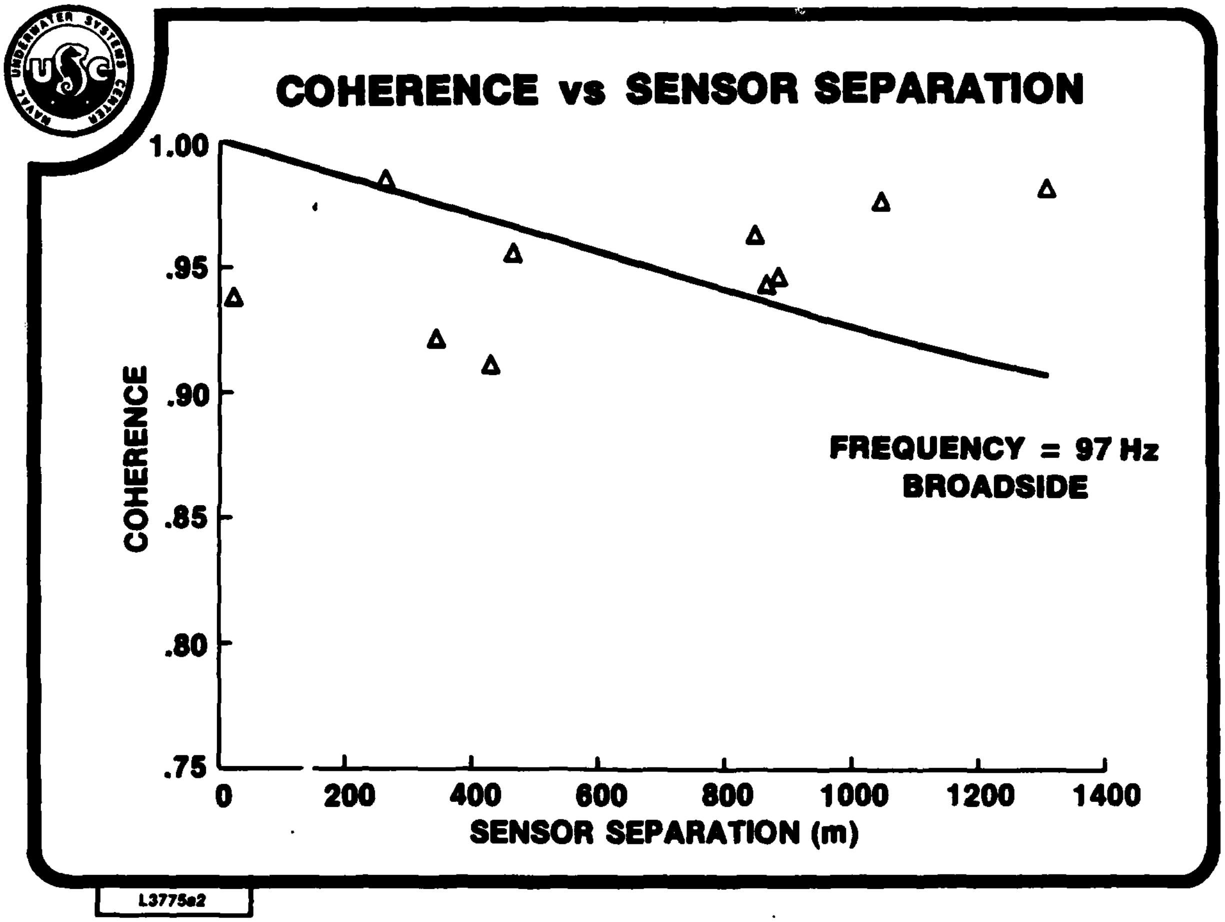

VUGRAPH 10

The highest frequency analyzed to date was 97 Hz. Only the coherence calculation was performed at this frequency and at broadside we still have very high coherence with the lowest value being about 0.91.

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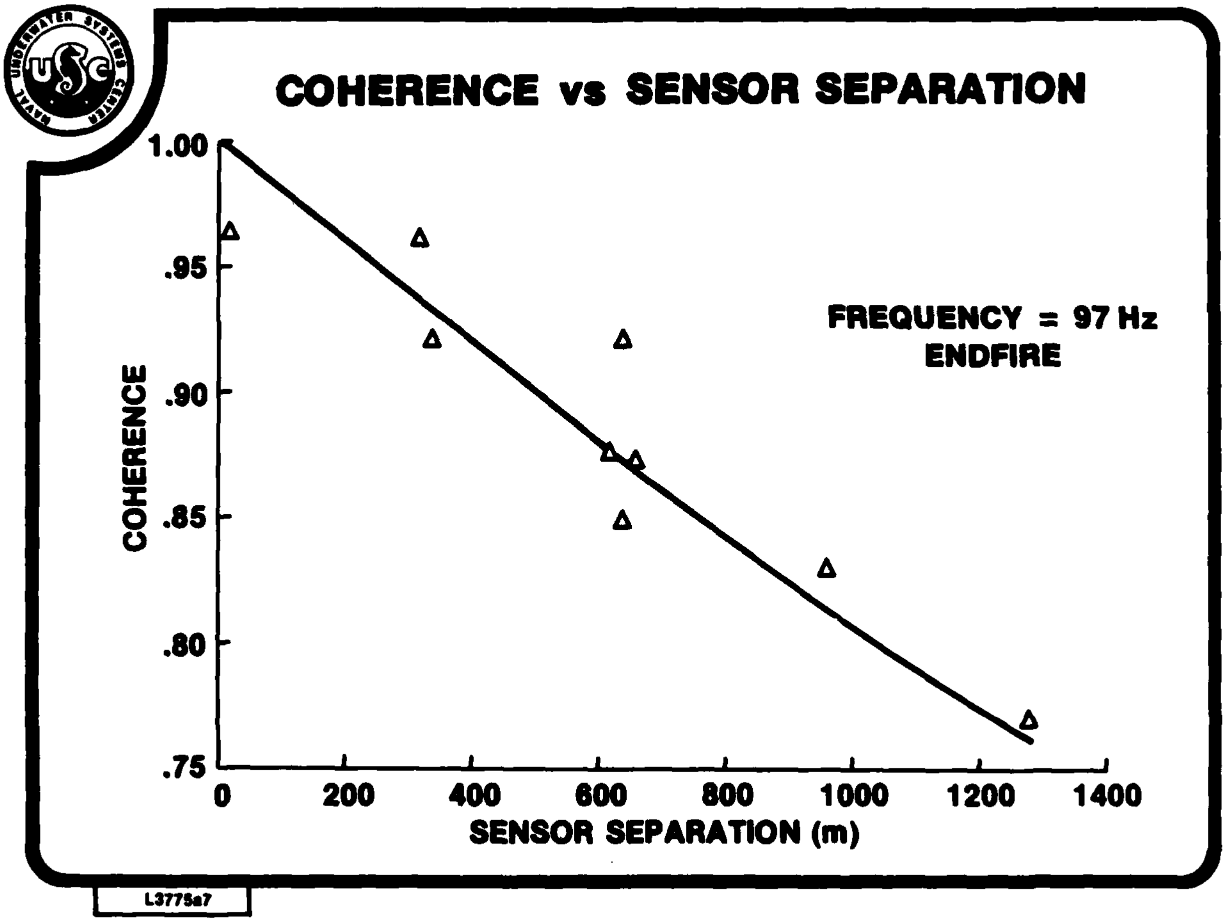
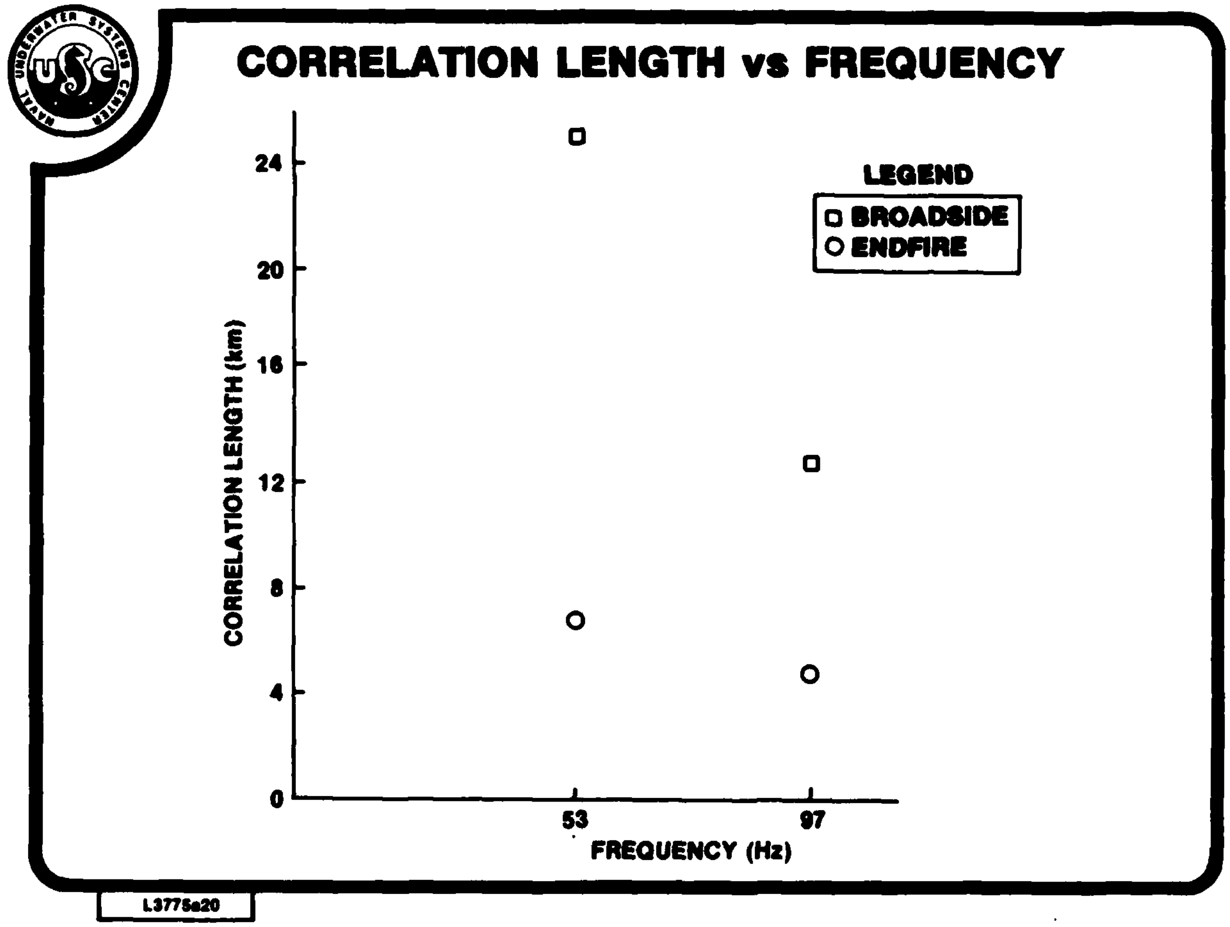


VUGRAPH 11

The largest degradation measured was endfire at 97 Hz. Note that even out at 1280 m the coherence is still above 0.75.

- Next vugraph, please. -



VUGRAPH 12

The correlation length determined from the exponential fit to the data is plotted as a function of frequency for both broadside and endfire. The trends are as expected; broadside is better than endfire and lower frequencies better than higher. Since the inferred correlation lengths are in every case larger than the array dimensions, these results should perhaps be viewed as order of magnitude estimates. To obtain more accurate estimates would require a much larger array, but it is clear that large correlation lengths are achievable in this environment with fixed sources and fixed receivers.

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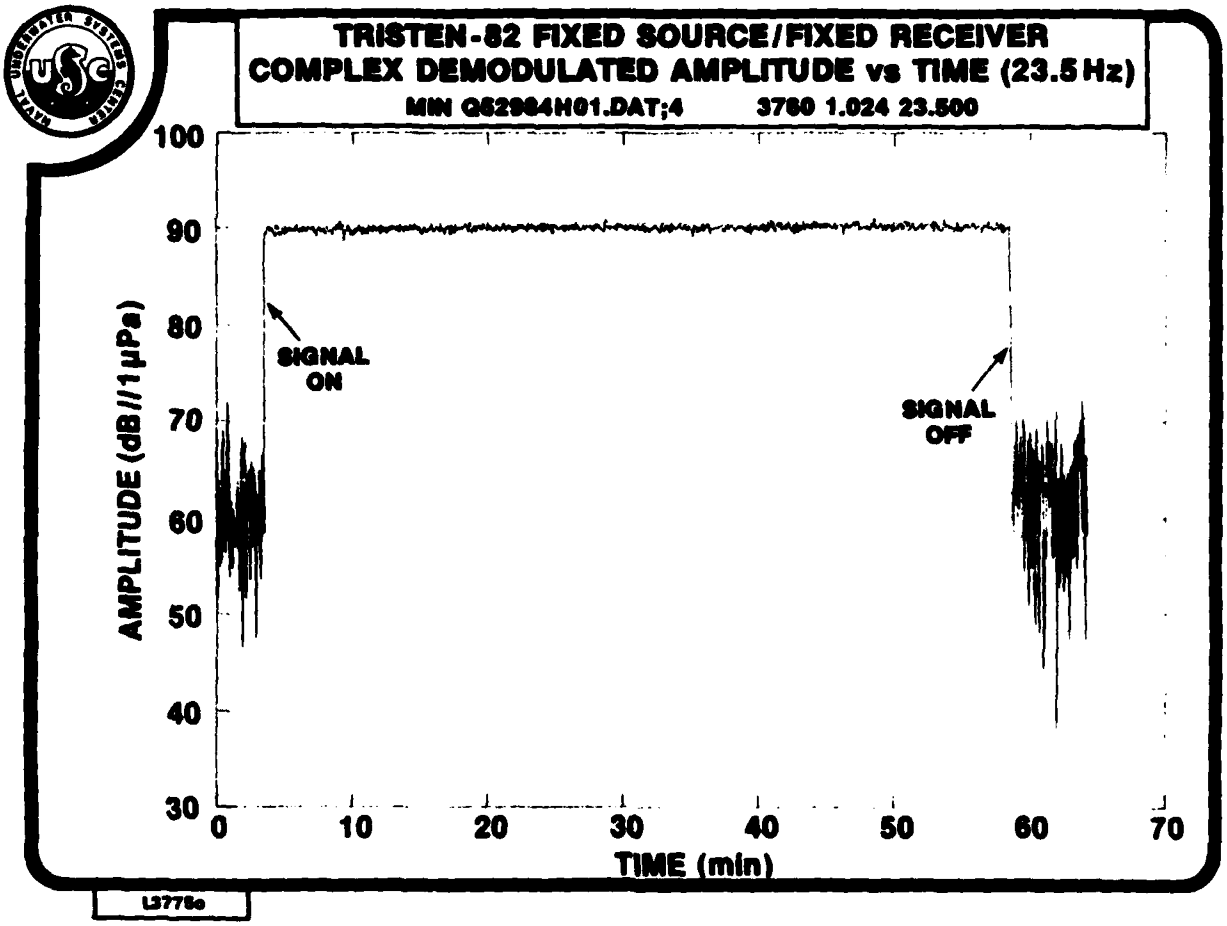

VUGRAPH 13

The stability of low frequency CW signals was examined at frequencies from 17.75 Hz to 97 Hz. Shown is the complex demodulated amplitude versus time at 23.5 Hz. The large jumps in amplitude at the beginning and end of the record represent the onset and termination of the signal. Evidence of temporal medium instability due to internal waves, currents, eddies, etc., would manifest itself as large changes in amplitude with time. None are observed. The small scale fluctuation in amplitude that can be observed is due to in-band noise following the observation of Mikhalevsky.

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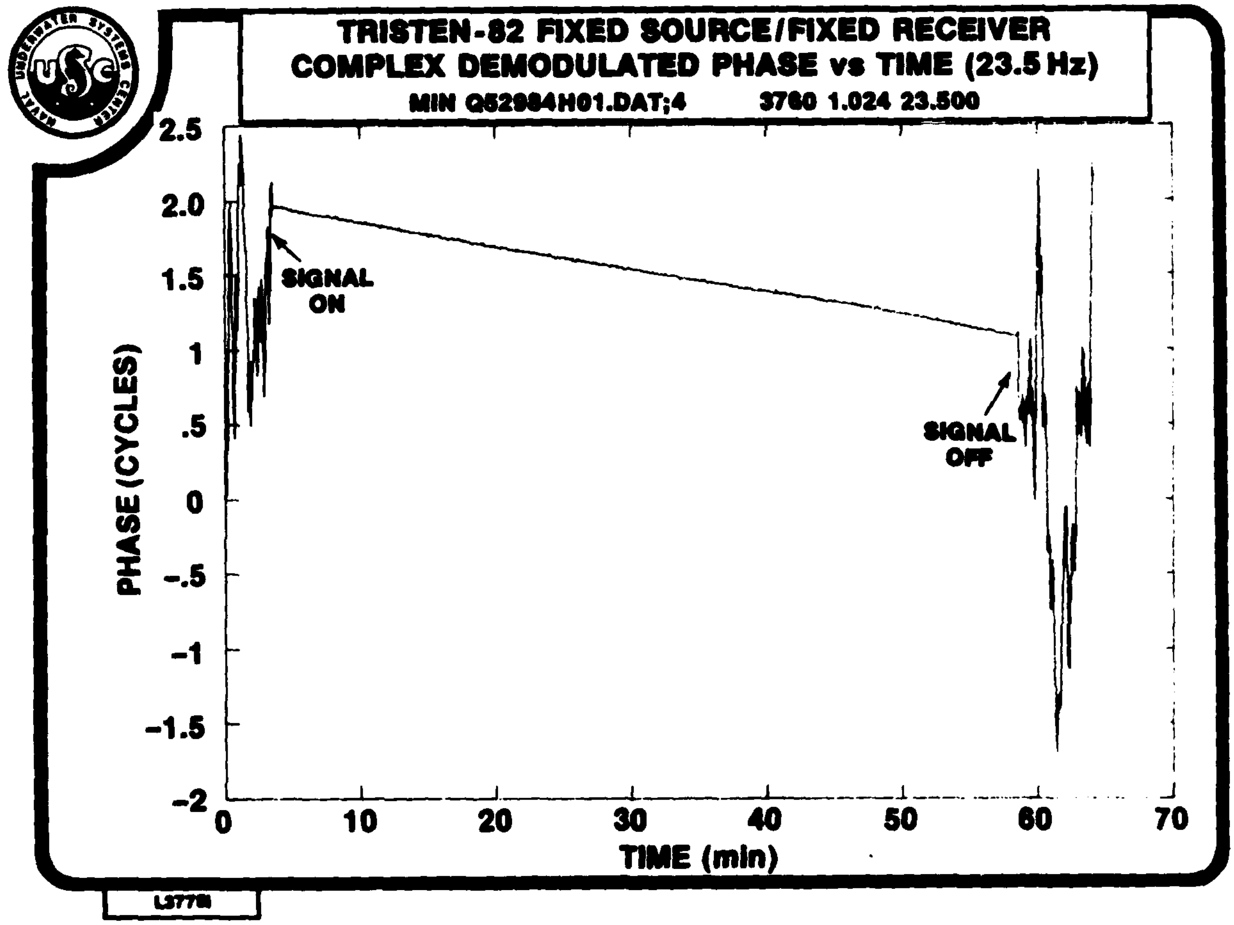

VUGRAPH 14

The complex demodulated phase versus time also shows no evidence of medium instability. The demodulation frequency chosen did not exactly match the received frequency which accounts for the non-zero constant slope.

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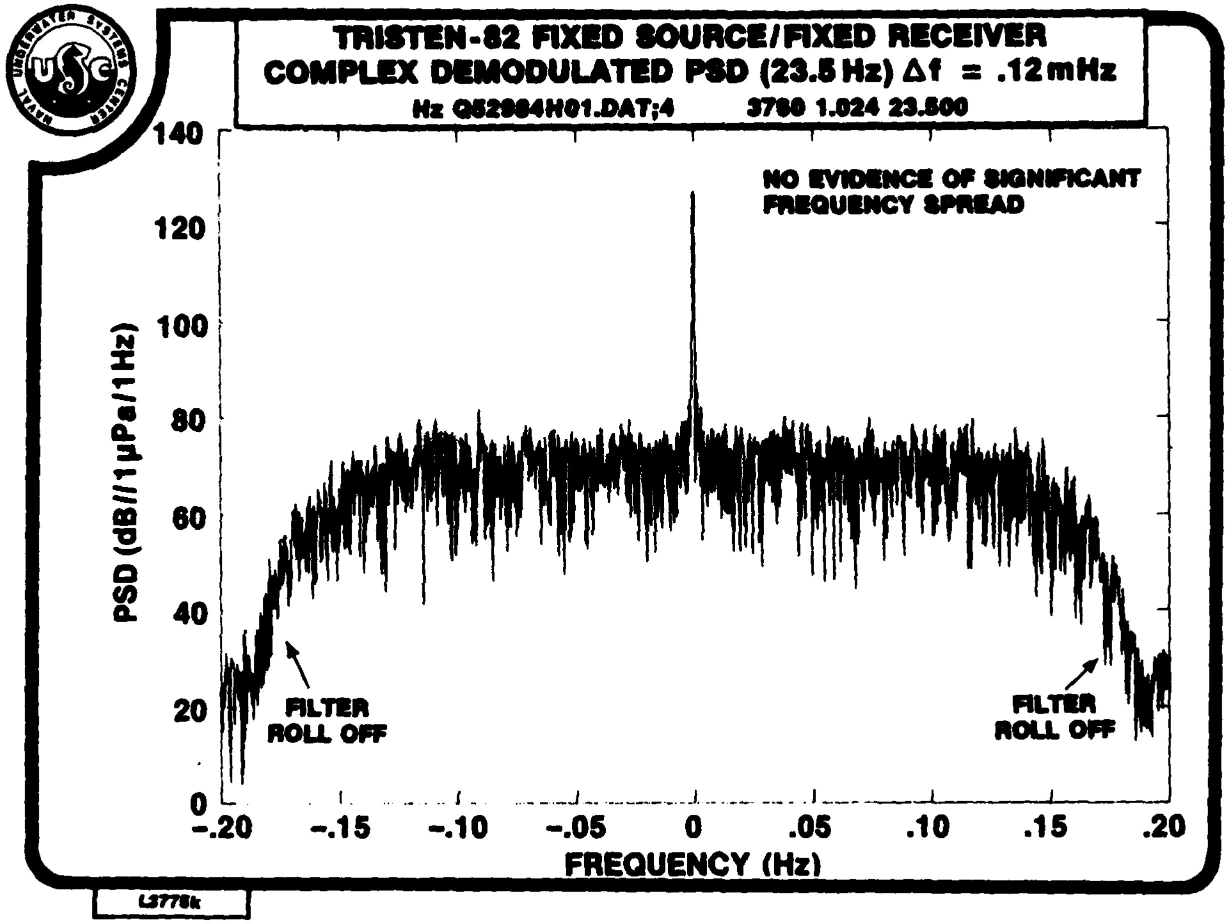
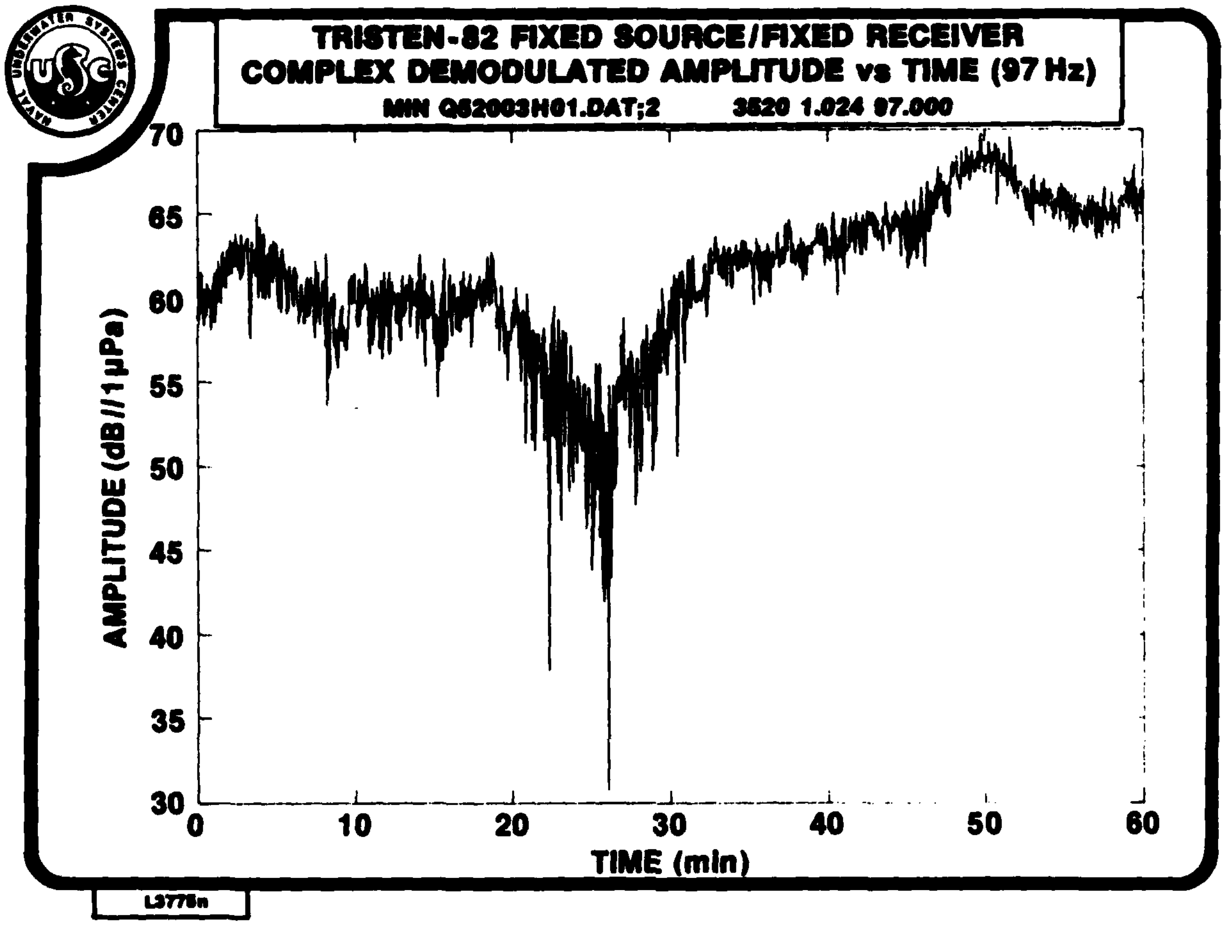


VUGRAPH 15

Considering that neither the amplitude nor phase of the signal showed any evidence of medium instability, one would expect that the spectrum would be a narrow spike centered at 23.5 Hz. Although the spike is narrow, it does widen near its base indicating that some frequency smearing does occur. It should be noted that this spreading occurs at levels at least 20 dB below the peak energy. A cumulative energy versus frequency analysis was performed to quantify the extent of the spreading in frequency and to determine the frequency band where the dominant energy is contained. The explanation of how this was done will be given shortly.

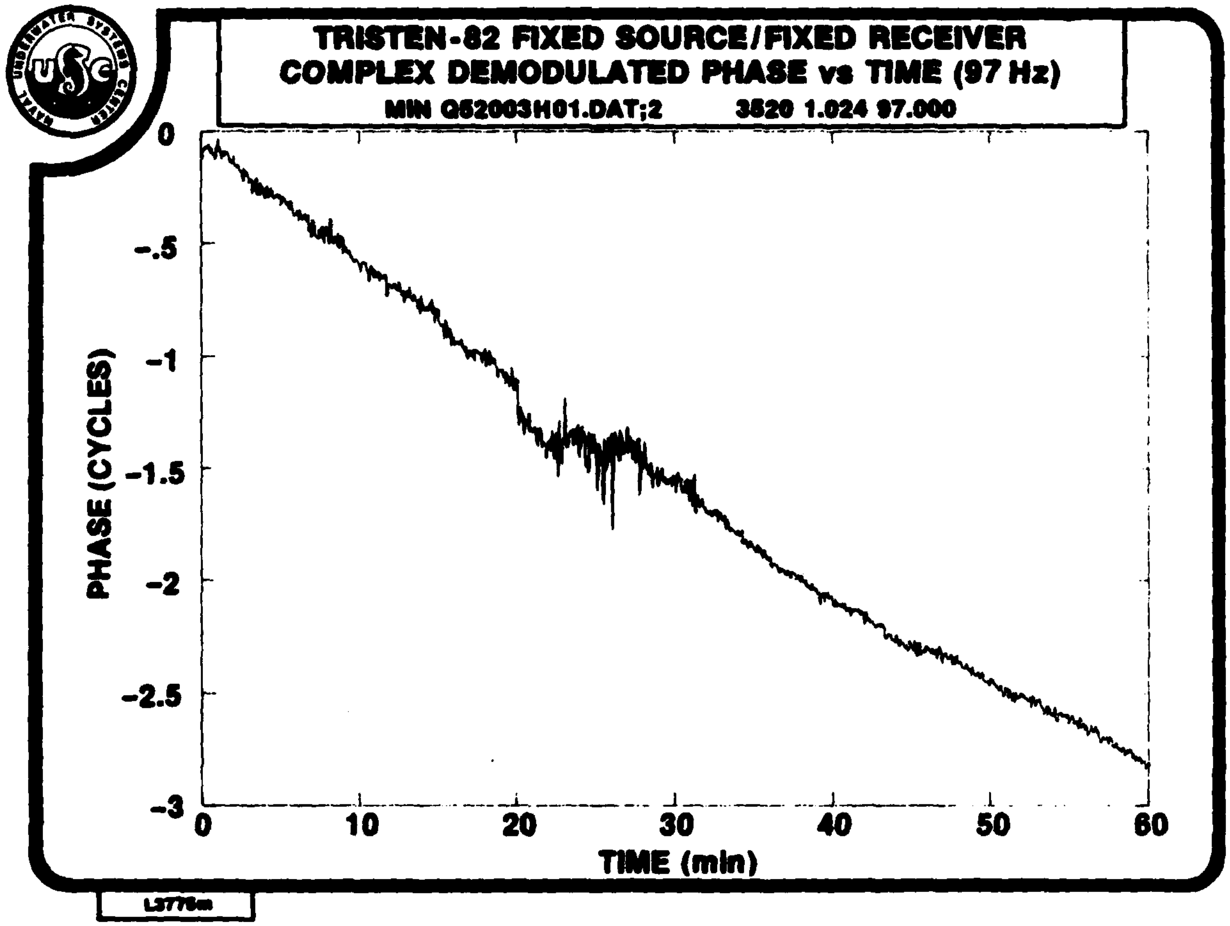
- Next vugraph, please. -



VUGRAPH 16

Shown is the complex demodulated amplitude versus time for 1 hour of a 2 hour transmission at 97 Hz. Unlike the result at the lower frequencies, there is now clear evidence of medium instability. The amplitude jitter is considerably stronger at 97 Hz and in the middle of the record the amplitude gradually decreases by about 10 dB and then recovers over a 10 minute period.

- Next vugraph, please. -



VUGRAPH 17

The complex demodulated phase versus time also shows evidence of a perturbation at about the same time as the 10 dB amplitude change.

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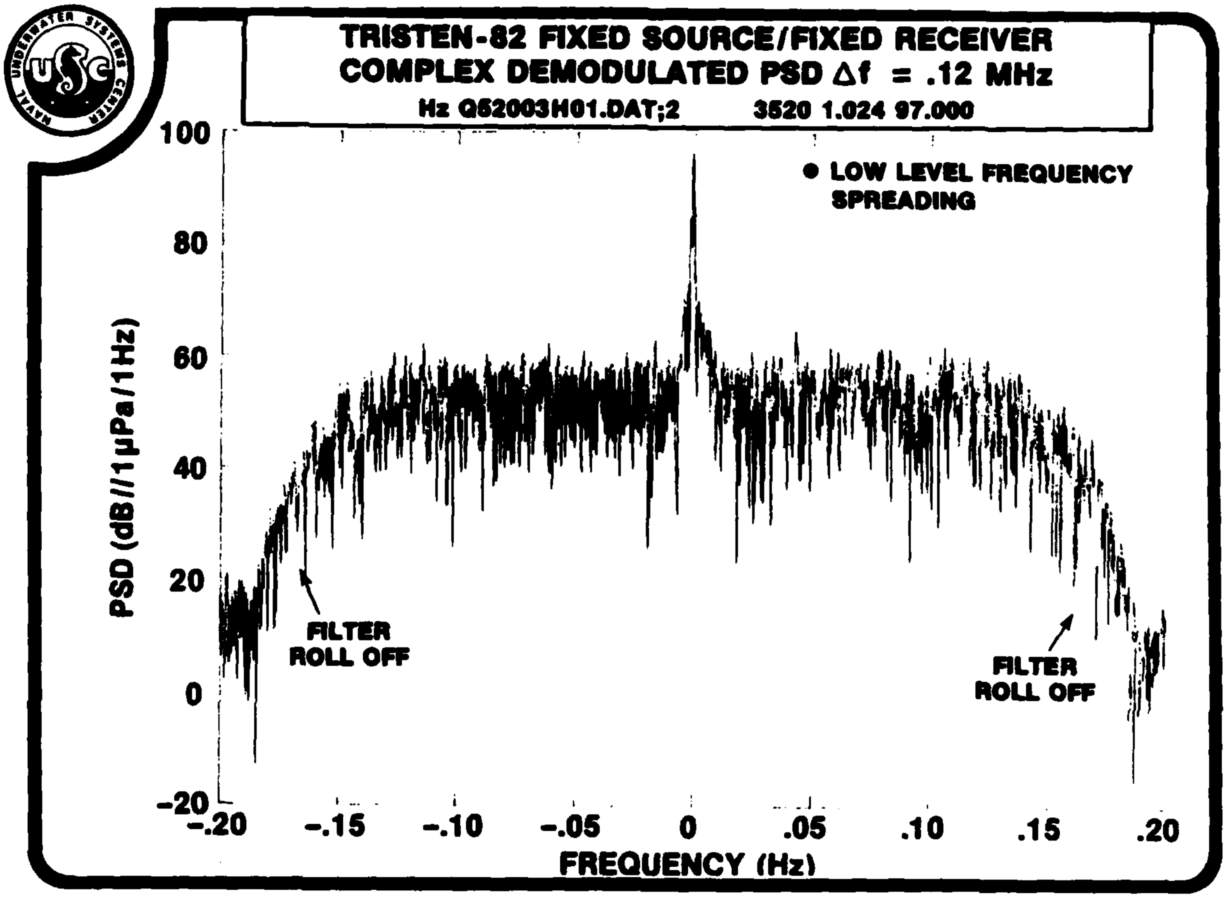
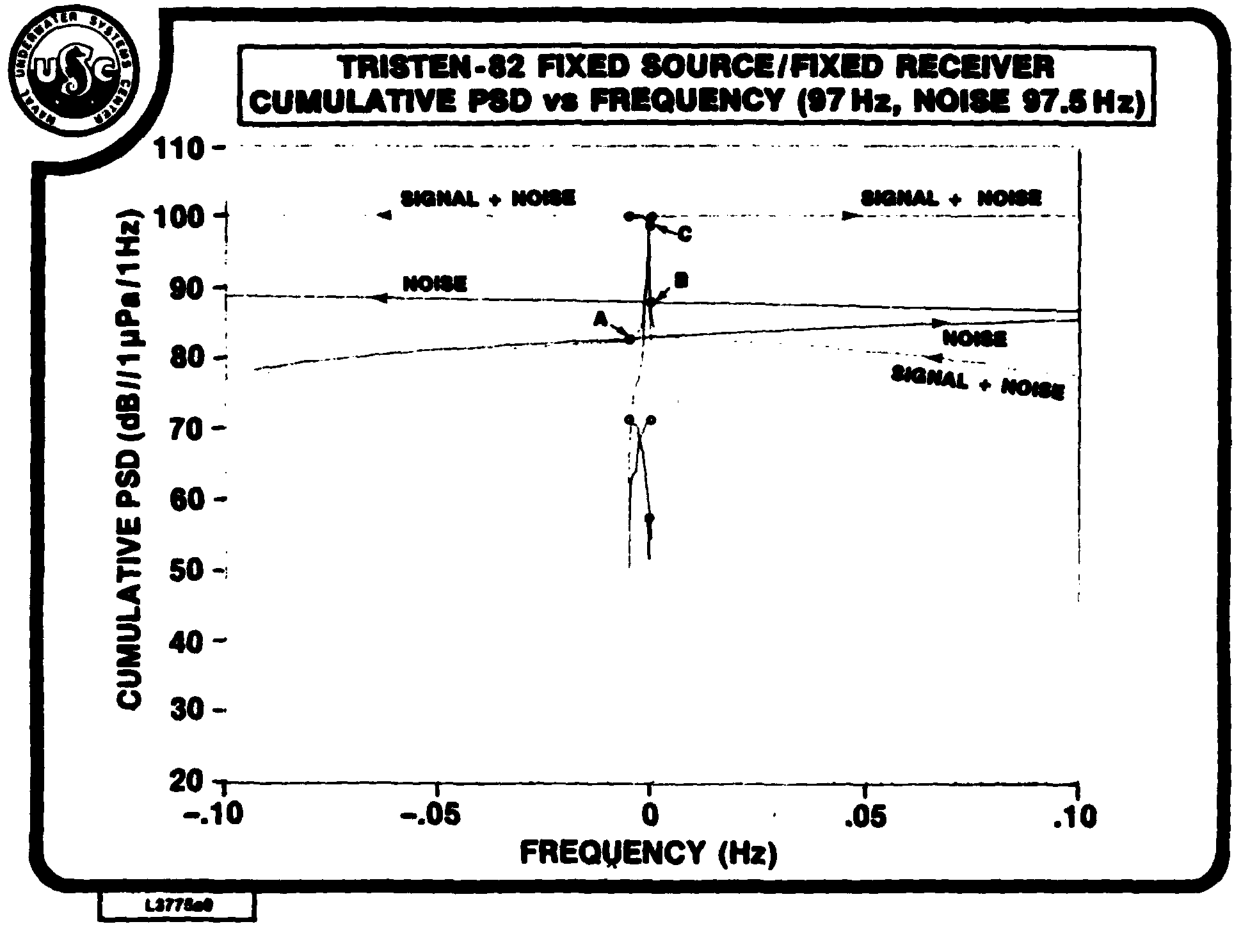


VUGRAPH 18

As one might expect, the energy is now spread over a wider frequency range. To determine the frequency spread, the cumulative energy of the signal plus noise was calculated starting from the low end of the filter and proceeding to the high end of the filter. The same calculation was made in the opposite direction. The point of intersection of these two results represents the median frequency. The entire demodulation process was redone at a nearby frequency outside of the filter that contains no signal energy. The cumulative noise-only energy was then obtained in the same manner as was done for the signal plus noise.

- Next vugraph, please. -



VUGRAPH 19

The top and bottom curves are the cumulative signal plus noise energy versus frequency going from left to right and right to left. Similar results for the noise only are also shown.

Starting at the left of the picture the lower signal plus noise and noise only curves gradually increase level as the frequency is increased from left to right. At point A the signal plus noise energy rises above the noise only energy and stays above it. Point A is thus the lowest frequency where signal energy exceeds the noise energy. Point B is found by the same process starting from the right. The frequency difference between A-B represents the bandwidth where the signal energy is above the noise. In this case that bandwidth is 5 mHz and the signal excess in this band is 22 dB. Most of the energy is contained in a much smaller bandwidth. This bandwidth was defined by coming down 3 dB from point C, which is the median frequency. In effect, this smaller bandwidth contains 75% of the signal excess. In this case, the smaller bandwidth was 0.4 mHz and contained 43 dB signal excess. Thus even in the case that showed the greatest evidence of medium instability, the significant frequency spread is exceptionally small.

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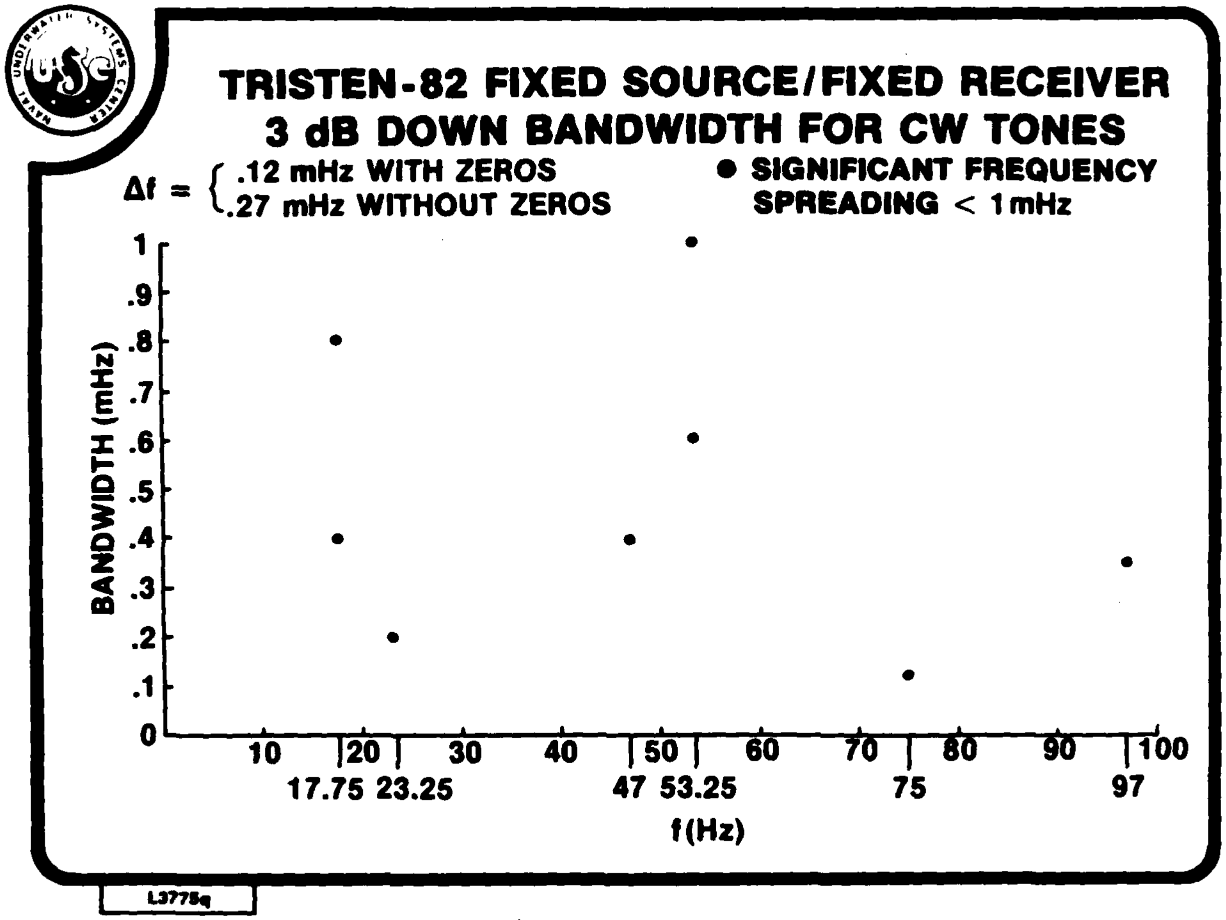

VUGRAPH 20

The 3 dB down bandwidths, plotted in tenths of mHz along the vertical axis, were determined for transmissions on different days at 17.75, 23.5, 47, 53.25, 75, and 97 Hz. At 17.75 and 53.25 Hz calculations from data on different days resulted in slightly different bandwidths. There appears to be no definite pattern to the results linking bandwidth with frequency other than the general conclusion that frequency spreading never exceeded 1 mHz at any frequency below 100 Hz.

- Last vugraph, please. -

TRISTEN-82
FIXED SOURCE/FIXED RECEIVER

CONCLUSIONS

SPATIAL CORRELATION

- LOW FREQUENCY SPATIAL CORRELATION LENGTHS ARE LARGE (WORST CASE WAS 4838 m AT 97 Hz)

STABILITY

- FREQUENCY SPREADING LIMITED TO LESS THAN 1 mHz (17 TO 97 Hz)

THUS

- LARGE PROCESSING GAINS CAN BE REALIZED IN THE DEEP ARCTIC OCEAN

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VUGRAPH 21

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